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EFFECT OF SONIC BOOM ASYMMETRY ON SUBJECTIVE LOUDNESS

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By

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SUMMARY

The NASA Langley Research Center's sonic boom apparatus was used in an experimental study to quantify subjective loudness response to a wide range of asymmetrical N-wave sonic boom signatures. Results were used to assess the relative performance of several metrics as loudness estimators for asymmetrical signatures and to quantify in detail the effects on subjective loudness of varying both the degree and direction of signature loudness asymmetry. Findings of the study indicated that Perceived Level (Steven's Mark VII) and A-weighted sound exposure level were the best metrics for quantifying asymmetrical boom loudness. Asymmetrical signatures were generally rated as being less loud than symmetrical signatures of equivalent Perceived Level. The magnitude of the loudness reductions increased as the degree of boom asymmetry increased, and depended upon the direction of asymmetry. These loudness reductions were not accounted for by any of the metrics. Corrections were determined for use in adjusting calculated Perceived Level values to account for these reductions. It was also demonstrated that the subjects generally incorporated the loudness components of the complete signatures when making their subjective judgments.

INTRODUCTION

An important objective of the NASA High-Speed Research Program (HSRP) is development of a technology base for future high-speed civil transport aircraft (HSCT). Such aircraft must be both environmentally acceptable and economically viable. Environmental issues that must be addressed include emissions and their relationship to ozone depletion, airport noise, and sonic booms. With regard to sonic booms, the HSRP seeks to quantify the potential benefits of sonic boom shaping, and determine a sonic boom exposure which would be acceptable to the general public. This is important because the economic viability of HSCT would be significantly enhanced if supersonic transports were allowed to fly over land at supersonic speeds.

In support of the HSRP sonic boom objectives, the NASA Langley Research Center is conducting laboratory studies, using a new sonic boom simulator, to quantify subjective loudness and annoyance of a wide range of simulated sonic boom signatures. The goals of these studies include identification of preferred signature shapes for minimum sonic boom loudness, development and refinement of a sonic boom loudness prediction model, and development of sonic boom acceptance criteria. Results can also be used to perform comparative evaluations of the loudness (and annoyance) of candidate "minimum boom" HSCT aircraft designs.

Loudness of simulated outdoor N-wave signatures were investigated in references 1 and 2. These studies described the results of paired comparison tests to assess the relative loudness of signatures defined

by various combinations of rise time, duration, and peak overpressure. It was shown that increased rise times resulted in substantial reductions in loudness for N-waves of constant overpressure. Other studies (references 3 and 4) suggested that sonic boom loudness can be reduced by more detailed shaping employing front shock minimization (FSM). This approach involved replacing the N-wave signatures with signatures in which the rise to peak overpressure was achieved in two distinct pressure ramps instead of one. It entailed decreasing the strength of the initial pressure rise (first pressure ramp) and then allowing a slower pressure rise to maximum overpressure (second pressure ramp). Results from references 3 and 4 showed that, for symmetrical FSM signatures, increasing front (and rear) shock rise time and/or decreasing front (and rear) shock overpressure were very effective in reducing subjective loudness without the necessity of reducing the absolute peak overpressure of a signature.

The study described in reference 4 included a limited number of asymmetrical signatures corresponding to candidate "low boom" aircraft designs. These asymmetrical boom signatures were rated by the subjects as being slightly less loud than FSM signatures having identical calculated loudness levels. However, since the number of asymmetrical booms included in the study was very limited, it was not possible to make definitive conclusions regarding the observed effect of asymmetry. Consequently, a follow-up experiment was conducted to investigate the effects of sonic boom asymmetry in detail.

It is the purpose of this paper to present the results of the follow-up sonic boom asymmetry study. In this study, sonic boom

asymmetry was intentionally introduced by systematically varying the rise times and peak overpressures of the front and rear shocks of simulated N-wave signatures. This resulted in a set of N-wave signatures in which the loudnesses of the front (compression) and rear (rarefaction) portions of each signature generally differed. Asymmetry was defined as the difference in calculated loudness level between the front and rear portion of each signature. Primary objectives were to (1) quantify subjective loudness as a function of both the degree and direction (that is, front louder than rear versus rear louder than front) of asymmetry, and (2) compare the loudness of symmetrical and asymmetrical signatures having equivalent calculated loudness levels.

EXPERIMENTAL METHOD

Sonic Boom Simulator

The experimental apparatus used in this study was the Langley Research Center's sonic boom simulator, which is described in detail in reference 2. The simulator, shown in figure 1, is a man-rated, airtight, loudspeaker-driven booth capable of accurately reproducing user-specified sonic boom waveforms at peak sound pressure levels up to 138-139 dB. Input waveforms were computer-generated and "pre-distorted" to compensate for the non-uniform frequency response characteristics of the booth. Pre-distortion was accomplished by use of a digital broadband equalization filter (see reference 5). Construction details, performance capabilities, and operating

procedures for the boom simulator are given in reference 2.

Test Subjects

Forty test subjects (25 female, 15 male) obtained from a subject pool of local residents were used in this study. Ages of the test subjects ranged from 18 years to 59 years with a median age of 33 years. All subjects were required to undergo audiometric screening prior to the test in order to ensure normal hearing.

Experimental Design

Test Stimuli.- The test stimuli consisted of N-wave signatures in which the rise times and peak overpressures of the front and rear shocks were systematically (and independently) varied. The duration of all signatures was 300 milliseconds. A typical asymmetrical signature is shown in figure 2. Specific factors included in the study were front shock rise time (τ_f), rear shock rise time (τ_r), front shock overpressure (ΔP_f), and rear shock overpressure (ΔP_r). Front and rear shock rise times selected for evaluation were 2, 3, and 6 milliseconds. Front and rear peak overpressures were each applied at five levels ranging from approximately 0.2 to 1.7 psf. Factorial combinations of these factors resulted in a total of 225 test stimuli. These were randomly assigned to five sessions of 45 stimuli each. To minimize order effects, the booms within each session were presented in both forward and reverse sequence. Boom session order was also

randomized and counterbalanced to further reduce order effects.

Scaling Method.- The scaling method used in this study was magnitude estimation. The validity and applicability of this method for measuring subjective loudness of sonic booms was demonstrated in a recent study (reference 6). In particular, the ratio properties of magnitude estimation scaling render it very useful for describing and interpreting loudness results obtained from sonic boom subjective response studies.

The magnitude estimation procedure used in this study is summarized as follows: A sonic boom stimulus, designated as the standard, was presented to a subject. This standard was assigned a loudness value of 100 by the experimenter. The standard was then followed by three comparison (test) stimuli. The task of a subject was to rate the loudness of each comparison stimulus relative to the loudness of the standard. For example, if a subject felt that a comparison stimulus was twice as loud as the standard, then he/she would assign it a value of 200. If the comparison stimulus was felt to be only one-fourth as loud as the standard, then the subject would assign it a value of 25. After the three comparison stimuli were evaluated, the standard was repeated and another three comparison stimuli judged. This standard-comparison sequence continued until the 45 test stimuli assigned to a session were evaluated. The subjects were free to assign any number of their choosing (except negative numbers) to reflect their loudness opinions. The instructions given to the subjects explaining how to use the magnitude estimation procedure are given in Appendix A. The magnitude estimation scoring sheets are

shown in Appendix B.

Test Procedure.- Subjects were delivered to the laboratory in groups of four, with one group in the morning and one group in the afternoon on any given day. Upon arrival at the laboratory each group was briefed on the overall purpose of the experiment, system safety features, and their rights as test subjects. A copy of these briefing remarks is given in Appendix C. The subjects were then given specific instructions related to the test procedure. At this point the subjects were taken individually from the waiting room to the sonic boom simulator. At the simulator the magnitude estimation scaling procedure was reviewed and the subject listened to several boom stimuli, played with the simulator door open, in order to become familiar with the type of sounds he/she would be asked to evaluate. The subject was then given a practice scoring sheet and seated in the simulator with the door closed. A practice session was then conducted in which the subject rated a set of practice stimuli similar to those used in the actual test session. Upon completion of the practice session the practice scoring sheet was collected and any questions were answered. The first test session was then conducted. After all subjects completed the first session they were then cycled through sessions 2 through 5. No further practice sessions were given.

Definition of Boom Asymmetry.- To understand the asymmetry results presented later, it is important to keep in mind how asymmetry was defined, calculated, and used in this study. The procedure was as follows: Each boom signature was played in the booth and measured (using a special low-frequency microphone) with the boo[illegible] [illegible]. These

measurements were made at a location within the booth corresponding approximately to the position occupied by the head of a seated subject. These measured signatures were then used to calculate Stevens Mark VII Perceived Level (PL) for the front part (PL_f), rear part (PL_r), and total signature (PL_{tot}). The procedure for calculating the PL loudness metric is given in reference 7. The difference (in dB) between PL_f and PL_r was defined as the signature asymmetry. Thus, asymmetry was not defined by peak overpressure, but by calculated loudness level. Note that positive values of asymmetry correspond to boom signatures in which the loudness of the front part is greater than the loudness of the rear part. If the rear part of a signature is loudest, then the value of asymmetry is negative.

Data Analysis

The measured boom pressure time histories were computer-processed to calculate sound exposure level in terms of three frequency weightings and to calculate two loudness metrics. The sound exposure level metrics were: (1) unweighted sound exposure level (L_{UE}), (2) C-weighted sound exposure level (L_{CE}), and (3) A-weighted sound exposure level (L_{AE}). The loudness metrics were Stevens Mark VII Perceived Level (PL) and Zwicker Loudness Level (LLZ). The calculation procedure for LLZ was based on the method described in reference 8.

The subjective data were characterized by calculating the geometric means of the magnitude estimates for each stimulus. It is customary (see reference 9, for example) to use geometric averaging

with magnitude estimation since the distribution of the logarithms of the magnitude estimates is approximately normal.

DISCUSSION OF RESULTS

Metric Considerations

Prior results (reference 4) indicated that PL, LLZ, and L_{AE} were all good estimators of the loudness of symmetrical sonic boom signatures. Consequently, it was of interest to determine if these results also applied to the asymmetrical signatures of the present study. The relative merits of the five metrics considered as estimators of loudness were evaluated by (1) calculating and comparing the correlation coefficients between each metric and the logarithms of the geometric means of the magnitude estimates and (2) performing linear regression analyses and comparing the standard errors of estimate of the best fit lines characterizing the subjective data for each metric. The dependent variables in each regression analysis were the logarithm of the geometric means, and the independent variables were the respective metric levels. The logarithm of the geometric means was used since subjective loudness is a power function of the physical intensity of a sound. Such a power function, when expressed in terms of the logarithm of the subjective loudness and acoustic pressure, is linear. The standard error of estimate for each regression line represents the scatter about the

line and is a measure of the prediction error, or "accuracy," of the regression model. The metric(s) with the lowest standard error(s) of estimate would be the most accurate predictor(s).

Correlation Analysis.- Pearson correlation coefficients were calculated for three cases: (1) the complete set of comparison booms, (2) the subset consisting of all symmetrical booms, and (3) the subset consisting of all asymmetrical booms. These are presented in Table 1. Note that all booms for which the difference between front (PL_f) and rear (PL_r) calculated loudnesses were between -1 dB and +1 dB were considered to be symmetrical. For each case the correlation coefficients between loudness ratings and the several metrics were based on metric levels calculated using: (1) the total boom signature; (2) the front part of the signature; (3) the rear part of the signature; and (4) either the front or rear part of the signature, whichever had the largest metric level (called the peak level). Consideration of (4) above permitted evaluation of whether the subjects' loudness responses were primarily influenced by the loudest portions of the signatures.

Detailed statistical analyses of the differences between the correlation coefficients in Table 1 indicated the following: The PL and L_{AE} metrics corresponding to the total and peak levels correlated highest with subjective loudness in all cases and did not differ significantly ($p<.001$) from one another. PL also correlated significantly higher ($p<.001$) than LLZ, although LLZ and L_{AE} did not differ significantly. The L_{CE} and L_{UE} metrics yielded the lowest correlations with subjective loudness. These findings are in agreement

with those of references 2 and 4.

Comparisons between the correlation coefficients of the asymmetrical signatures in Table 1 for each of the four signature definitions defined earlier (that is, total, front, rear, and peak level) show that, for all metrics, the highest correlation coefficients were obtained for metric levels calculated using either the total signature or the peak level of the signature. Statistical comparisons between the total and peak level correlation coefficients for each metric indicated that the correlations based on total metric level were generally significantly higher ($p<.001$) than those based on peak level. This implies that the subjects generally "listened to" and incorporated the loudness components of the complete signatures when reporting their subjective loudness judgments. Correlation coefficients based on either the front or rear metric levels were substantially lower than those obtained for the total and peak level cases. Note also that, for the asymmetrical booms, the correlations based on the front part of the booms were higher than those based on the rear part for all metrics except L_{UE}. For the symmetrical booms, the front and rear correlations were approximately equal.

The low correlations between subjective loudness ratings and metric levels calculated for the front shock alone indicated that the subjective perceptions were not dominated by the initial shock. This shows that loudness was not dominated by "startle effects" within the laboratory environment. Such effects, however, may be present within realistic in-home situations.

The correlation coefficients discussed above measured the degree

of relationship between the subjective ratings and each metric. They were proportional to the amount of variance in the subjective ratings that was "explained" by a metric and, hence, provided initial information for assessing metric performance. To more fully assess each metric as a loudness estimator for asymmetrical signatures, the relative prediction accuracy of each of the five metrics was considered. The parameter used to assess prediction accuracy of each metric was the standard error of estimate obtained from the regression analysis procedure discussed earlier. These are presented in Table 2 for each of the cases defined in Table 1.

The data of Table 2 for the asymmetrical signatures show that the lowest standard errors of estimate were obtained for the PL, L_{AE}, and LLZ metrics, with PL and L_{AE} being approximately equal and slightly smaller than those obtained for LLZ. The data also show that the smallest standard errors of estimate were obtained from the regression analyses using the total metric levels. Analyses using the peak metric level resulted in standard errors of estimate that were between 14 and 44 percent larger than those obtained for the total level. The largest standard errors of estimate occurred for the front and rear metric levels. Based upon these results, and the correlation analysis results discussed earlier, it is seen that the PL and L_{AE} metrics performed best and were good estimators of subjective loudness for the asymmetrical signatures. The small standard errors of estimate obtained for the total signatures provided additional evidence that the subjects based their judgments on the total signatures. However, the signatures of this study were all of 300-millisecond duration.

Sonic boom signatures of substantially shorter duration (less than 200 milliseconds) could be subject to temporal masking effects that would produce results different from those presented herein. The front and rear portions of booms having substantially longer durations would likely be treated as separate events and rated accordingly.

Sonic Boom Asymmetry Effects

The overall effect of sonic boom asymmetry on subjective loudness response is displayed in figure 3. Shown are the logarithm of the geometric means of the magnitude estimates as a function of total PL for the symmetrical and asymmetrical boom subsets. The solid and dashed lines represent the best-fit lines to the data for the symmetrical and asymmetrical signature subsets respectively. (Note that the asymmetrical signature data encompass a range of asymmetries that vary from approximately -20 dB to +20 dB). These data show that the asymmetrical signatures were, for equal PL, generally rated as less loud than the symmetrical signatures. Dummy variable regression analysis indicated these differences in overall loudness response to be significant ($p<.02$).

The overall asymmetry effect described above was based upon the complete stimuli set and represents the "average" effect of boom asymmetry. It is more useful, however, to consider the effects associated with varying degrees of signature asymmetry. The particular parameters of interest were the degree of asymmetry (defined as the difference between the PL of front and rear parts of a

signature, that is, $PL_f - PL_r$) and the "direction" of the asymmetry (that is, front largest or rear largest). The effects of both the degree and direction of asymmetry are displayed in figures 4(a) - 4(d) for signature loudness asymmetries of approximately ±4, ±8, ±12, and ±16 dB. Shown on each plot are the linear regression lines relating the logarithm of the geometric means of the magnitude estimates and total PL for (a) the signatures which have zero or very small (within ±1 dB) loudness asymmetries (heavy solid lines); (b) the signatures for which loudness of the front is greatest (dashed lines); and (c) those signatures for which the loudness of the rear is greatest (thin solid lines). The regression lines representing the signatures with zero or very small loudness asymmetry are labeled as symmetrical and are identical in each plot.

The results in figures 4(a) - 4(d) show that the loudness of the asymmetrical signatures, for each degree of asymmetry, was generally less than the loudness of symmetrical signatures of equivalent total PL. Also, the magnitude of the loudness reduction increased as the degree of asymmetry increased. This is evidenced by consecutive inspection of figures 4(a) - 4(d). Of particular interest is the fact that loudness reduction due to asymmetry also depended upon which half of the signature was loudest. For example, figure 4(d) [for $PL_f - PL_r = \pm 16$ dB] shows that the loudness ratings of the asymmetrical signatures in which the rear shock was loudest were significantly less than those for which the front shock was loudest. This effect diminished with decreasing asymmetry.

The effect of signature asymmetry is summarized in figure 5 in

terms of the reductions, or changes, in calculated total PL as a function of the degree of asymmetry, $PL_f - PL_r$. This curve was obtained from a multiple regression analysis, with logarithm of the magnitude estimates as the dependent variable and total PL and degree of asymmetry as the independent variables. Asymmetry was included up to third order in the analysis. The changes in loudness due to asymmetry alone were obtained by removing from the regression model the effect due to total PL. These loudness changes were then converted to equivalent PL values using the regression coefficient for PL.

Figure 5 shows that loudness reductions increased as the degree of asymmetry became increasingly negative ($PL_b >> PL_r$). Loudness reductions equivalent to about 3 dB in total PL were observed at asymmetries of approximately -20 dB. Only minor reductions in loudness occurred for positive asymmetry values. These effects were not accounted for by any of the loudness metrics. Further, they do not appear to be accounted for by temporal masking since the delay between the front and rear shocks of these signatures was about 300 milliseconds and significant temporal masking effects generally are limited to delay times of less than 200 milliseconds (reference 10). It is possible that some type of "psychological" masking occurred in which the loudness, or presence, of a weaker front shock tended to divert, or mask, the attention of the subjects such that the rear shocks were not perceived to be as loud as they would have been in the absence of a front shock. This is speculative, however, and further investigation of asymmetry effects may be warranted in order to gain additional understanding of these results.

CONCLUDING REMARKS

The NASA Langley Research Center's sonic boom apparatus was used in an experimental study to quantify subjective loudness response to a wide range of simulated asymmetrical N-wave sonic boom signatures. Results were used to assess the relative performance of several metrics as loudness estimators for asymmetrical signatures and to quantify in detail the effects on subjective loudness of varying both the degree and direction of signature loudness asymmetry. Specific conclusions and comments pertinent to the results of this study are summarized as follows:

(1) The best metrics for use as estimators of subjective loudness for asymmetrical signatures were Perceived Level, PL, and A-weighted sound exposure level, L_{AE}. These were significantly better estimators than either C-weighted or unweighted sound exposure level.

(2) The highest correlation coefficients between subjective loudness response and metric level were obtained for metric levels calculated using the total signatures. Although the correlations of loudness response with the largest of the calculated front or rear metric levels were also high, they were significantly lower than those based on the total signatures. This indicates that the subjects generally incorporated the loudness components of the complete signatures when making their subjective judgments. The

low correlations obtained between loudness ratings and the metric levels calculated for the front shock alone further imply that the subjective loudness perceptions of asymmetrical sonic booms were not overly influenced by the initial shock.

(3) The results of this study were based on signatures having durations of approximately 300 milliseconds. Caution should be used when applying these results to signatures having significantly different durations.

(4) The asymmetrical signatures were generally rated as being less loud than symmetrical signatures of equivalent total PL. The magnitude of the loudness reductions increased as the degree of asymmetry increased, and depended upon the direction of the asymmetry. Loudness reductions of about 3 dB in PL were observed for signatures in which the loudnesses of the rear portion of the signature exceeded those of the front portion by 20 dB. When the loudnesses of the front portion of the signatures exceeded those of the rear by 20 dB, the loudness reductions were less than 0.5 dB in PL.

(5) The loudness reductions due to asymmetry were not accounted for by any of the metrics. Loudness corrections were determined for use in adjusting the calculated PL values to account for the effects of asymmetry.

(6) Temporal masking does not appear to account for the observed asymmetry effects since the delay times between the front and rear shocks of the signatures in this study were larger than those known to produce temporal masking effects. It is possible that the

front shocks, particularly those that were less loud than the rear shocks, diverted the subjects' attention such that the full loudness impact of the rear shocks was not realized.

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Table 1 - Correlation coefficients between each metric and the logarithm of the geometric means for various test parameters.

Metric	**Calculated For**	**All Booms (N=225)**	**Symmetrical (N=27)**	**Asymmetrical (N=198)**
PL	Total	0.9705	0.9844	0.9683
	Front	0.7321	0.9837	0.7001
	Back	0.5924	0.9840	0.5333
	Peak	0.9397	0.9837	0.9463
LLZ	Total	0.9564	0.9727	0.9531
	Front	0.7197	0.9656	0.6887
	Back	0.5827	0.9747	0.5239
	Peak	0.9254	0.9684	0.9284
L_{AE}	Total	0.9680	0.9862	0.9657
	Front	0.7315	0.9852	0.6989
	Back	0.5855	0.9736	0.5259
	Peak	0.9423	0.9799	0.9475
L_{CE}	Total	0.9127	0.9343	0.9077
	Front	0.7044	0.9165	0.6767
	Back	0.5725	0.9334	0.5191
	Peak	0.8784	0.9114	0.8769
L_{UE}	Total	0.8644	0.9013	0.8566
	Front	0.5650	0.8585	0.5358
	Back	0.6349	0.8987	0.5907
	Peak	0.8164	0.8900	0.8055

Table 2.- Standard errors of estimate of the linear regression lines for each metric and the logarithm of the geometric means for various test parameters.

Metric	**Calculated For**	**All Booms (n=225)**	**Symmetrical (N=27)**	**Asymmetrical (N=198)**
PL	Total	0.0326	0.0307	0.0324
	Front	0.0920	0.0314	0.0927
	Back	0.1089	0.0312	0.1098
	Peak	0.0462	0.0314	0.0420
LLZ	Total	0.0394	0.0406	0.0393
	Front	0.0938	0.0454	0.0941
	Back	0.1098	0.0390	0.1105
	Peak	0.0512	0.0436	0.0482
L_{AE}	Total	0.0339	0.0289	0.0337
	Front	0.0921	0.0299	0.0928
	Back	0.1095	0.0399	0.1104
	Peak	0.0452	0.0348	0.0415
L_{CE}	Total	0.0552	0.0623	0.0545
	Front	0.0959	0.0699	0.0956
	Back	0.1108	0.0626	0.1109
	Peak	0.0646	0.0719	0.0624
L_{UE}	Total	0.0680	0.0756	0.0670
	Front	0.1115	0.0896	0.1096
	Back	0.1044	0.0766	0.1047
	Peak	0.0780	0.0796	0.0769

Appendix A.- Magnitude Estimation Instructions

SPECIFIC INSTRUCTIONS

This test will consist of five test sessions. Prior to the first test session each of you will be taken individually to the simulator where you will listen to sounds that are similar to those you will be asked to rate. We will then place you in the simulator and a practice scoring session will be conducted. Upon completion of the practice session we will collect the practice rating sheets and answer any questions you may have concerning the test. At this point the first actual test session will be conducted. You will then return to the waiting room while the other members of your group complete similar tests. You will return to the simulator four more times to complete the remaining four test sessions.

During a test session we will play a series of sonic booms over the loudspeakers in the door of the simulator. The first sonic boom that you hear, and every fourth boom thereafter, will be a **REFERENCE** boom that you will use to judge how loud the other booms are. In order to help you keep track of which boom is the **REFERENCE** boom, it will always be preceded by a short beep. The **REFERENCE** boom will remain the same throughout the test. Your task will be to tell us how loud the each of the other booms are as compared to the **REFERENCE** boom. You will be provided rating sheets for use in making your evaluations. The rating sheets will indicate when a **REFERENCE** boom will be played and the sequence of **REFERENCE** and other booms will be organized as follows:

```
  <--------------------beep
R=100 <----------------reference
1. ________
2. ________
3. ________
  <--------------------beep
R=100 <----------------reference
4. ________
5. ________
6. ________
```

The scoring procedure will be as follows: The short beep will indicate to you that the boom which follows is the **REFERENCE** boom. Please listen to it carefully because you will compare the other booms to it. For this purpose the **REFERENCE** boom will be assigned a loudness value of 100. Thus you do not score the **REFERENCE** boom because it will always be equal to 100. You will then hear a sequence of three comparison booms. After listening to each comparison boom you should decide how loud you think it is relative to the **REFERENCE** boom and assign it a number accordingly. This number will be entered on the appropriate line of the scoring sheet. For example, if you feel the

comparison boom is three times louder than the **REFERENCE** boom then you would give it a loudness score of 300. If you think the comparison boom is only one-fourth the loudness of the **REFERENCE** you would give it a loudness score of 25. You may choose any number you wish as long as it faithfully represents your impression of the relative loudness of the comparison and **REFERENCE** booms. After evaluating three comparison booms in this manner you will hear the beep again, followed by the **REFERENCE** boom and three more comparison booms. This will be repeated within a test session until a total of 45 comparison booms have been scored. Remember! There are no right or wrong answers. We are interested only in how loud the booms sound to you.

Appendix B.- Sample Scoring Sheet

Subject#__________ I.D.________________ Date____________

Rating Sheet

R=100

1. ________
2. ________
3. ________

R=100

4. ________
5. ________
6. ________

R=100

7. ________
8. ________
9. ________

R=100

10. ________
11. ________
12. ________

R=100

13. ________
14. ________
15. ________

R=100

16. ________
17. ________
18. ________

R=100

19. ________
20. ________
21. ________

R=100

22. ________
23. ________
24. ________

R=100

25. ________
26. ________
27. ________

R=100

28. ________
29. ________
30. ________

R=100

31. ________
32. ________
33. ________

R=100

34. ________
35. ________
36. ________

R=100

37. ________
38. ________
39. ________

R=100

40. ________
41. ________
42. ________

R=100

43. ________
44. ________
45. ________

Appendix C.- General Briefing Remarks

GENERAL INSTRUCTIONS

You have volunteered to participate in a research program designed to evaluate various sounds that may be produced by certain aircraft. Our purpose is to study people's impressions of these sounds. To do this we have built a simulator which can create sounds similar to those produced by some aircraft. The simulator provides no risk to participants. It meets stringent safety requirements and cannot produce noises which are harmful. It contains safety features which will automatically shut the system down if it does not perform properly.

You will enter the simulator, sit in the chair, and make yourself comfortable. The door will be closed and you will hear a series of sounds. These sounds represent those you could occasionally hear during your routine daily activities. Your task will be to evaluate these sounds using a method that we will explain later. Make yourself as comfortable and relaxed as possible while the test is being conducted. You will at all times be in two-way communication with the test conductor, and you will be monitored by the overhead TV camera. You may terminate the test at any time and for any reason in either of two ways: (1) by voice communication with the test conductor or (2) by exiting the simulator.

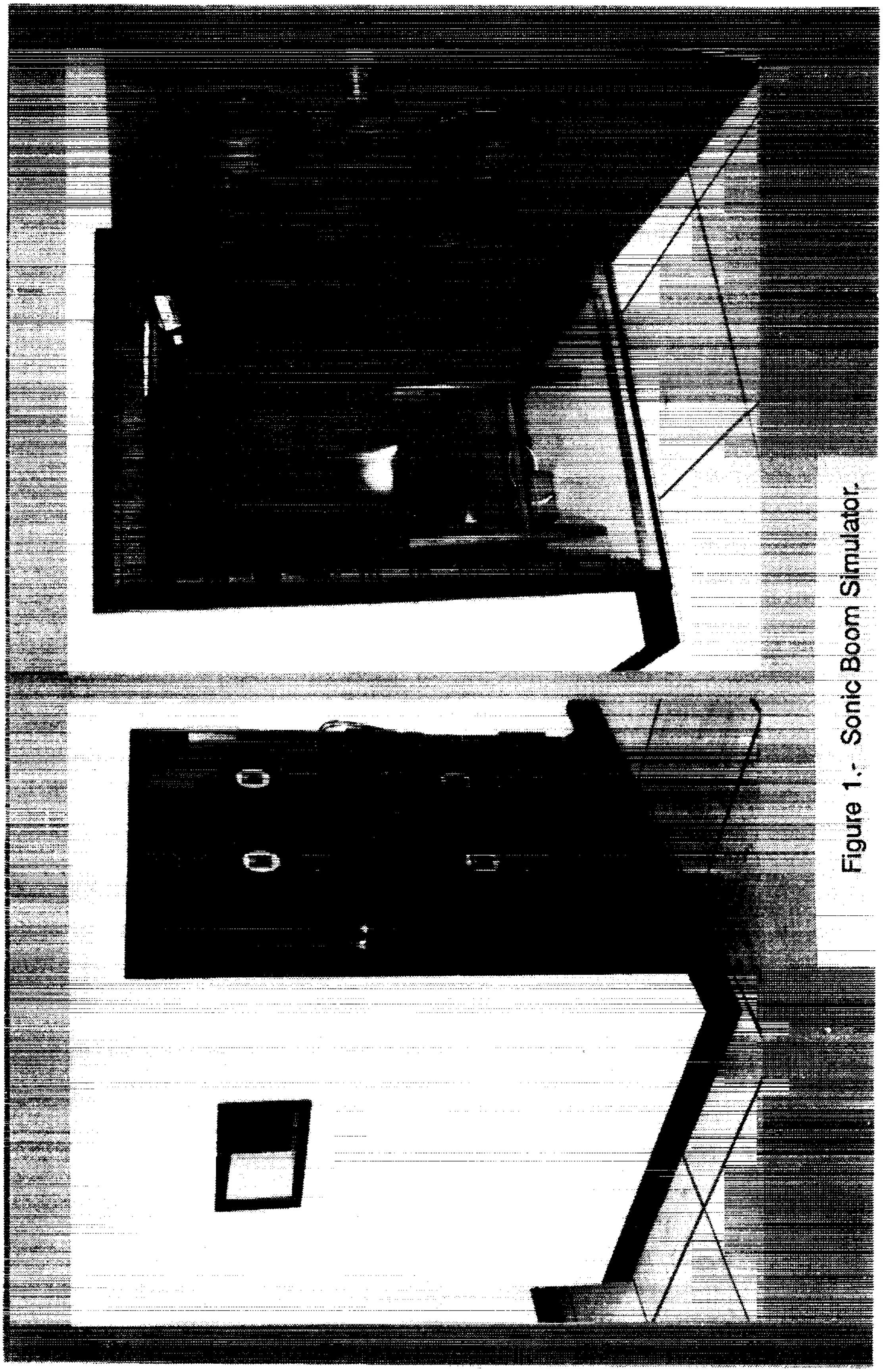


Figure 1.- Sonic Boom Simulator.

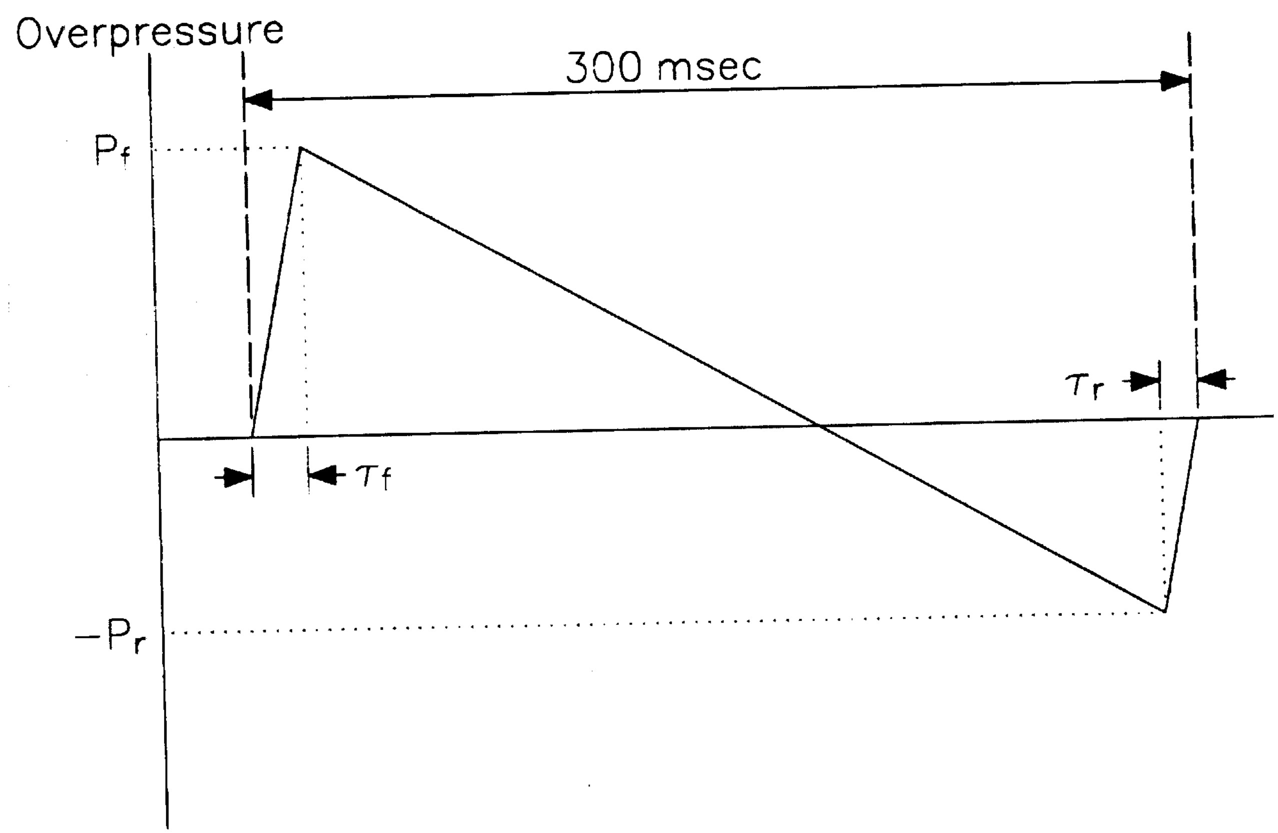


Figure 2.— Asymmetrical signature parameters

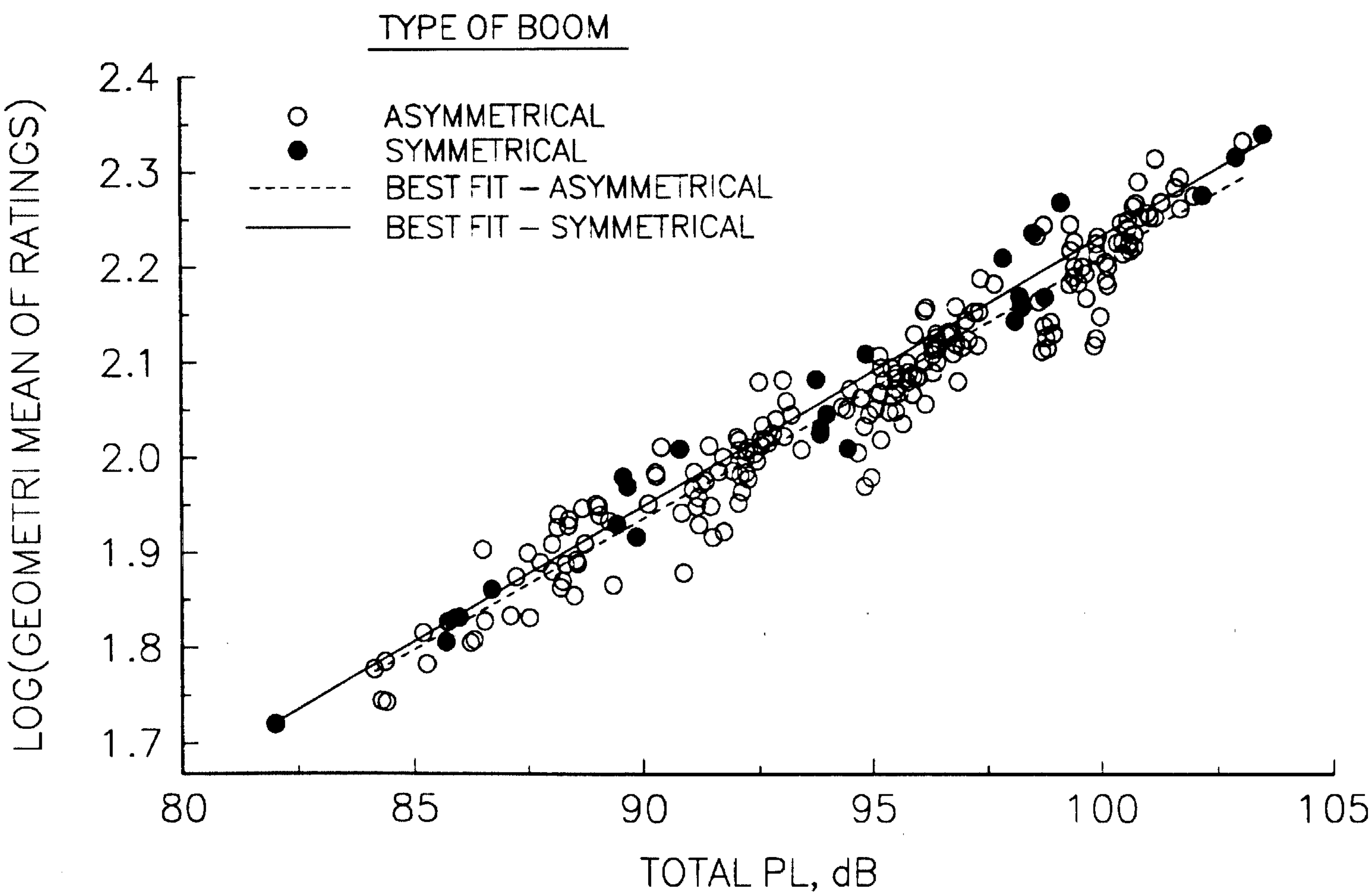
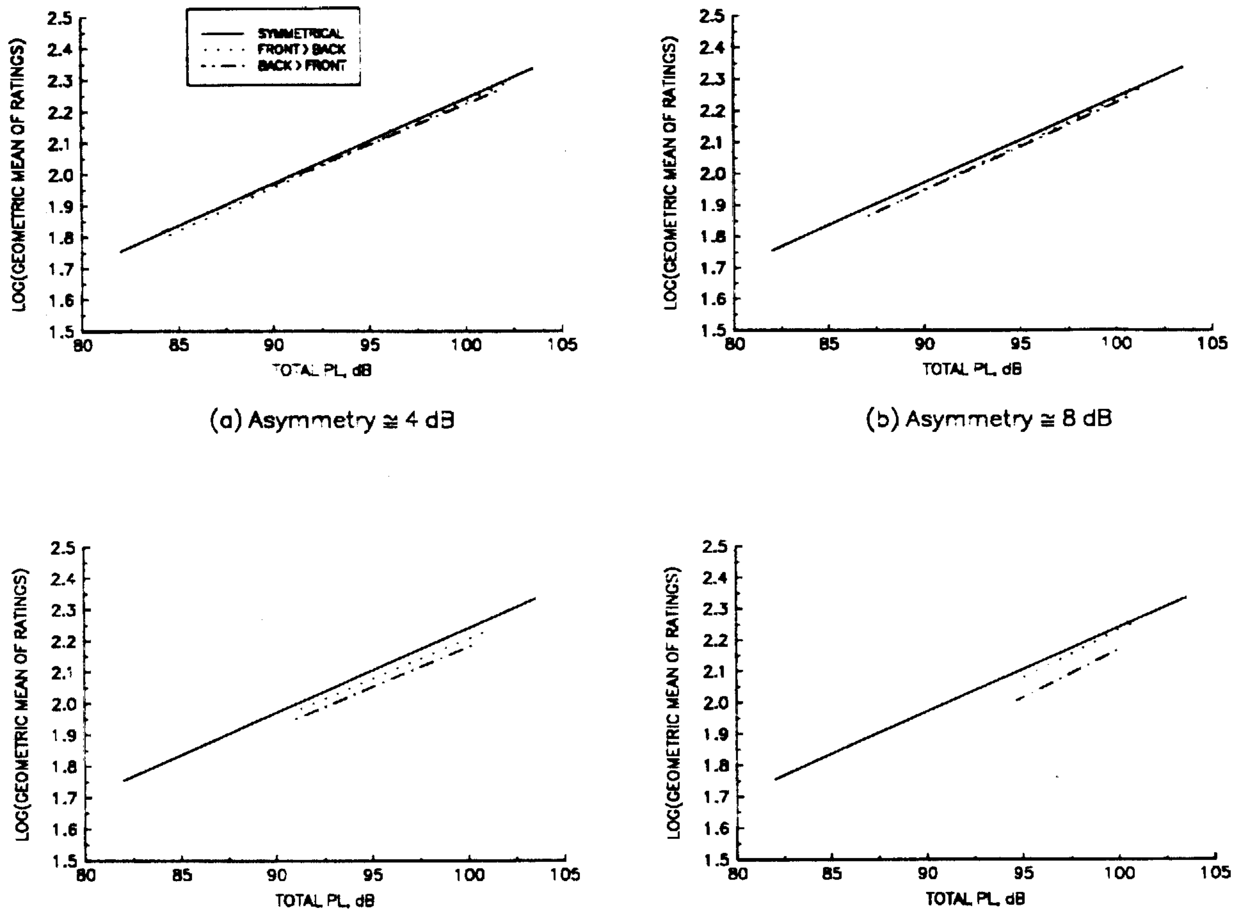


Figure 3.– Subjective loudness of symmetrical and asymmetrical booms.



(a) Asymmetry ≅ 4 dB

(b) Asymmetry ≅ 8 dB

(c) Asymmetry ≅ 12 dB

(d) Asymmetry ≅ 16 dB

Figure 4.— Loudness effects of N—wave signature asymmetry.

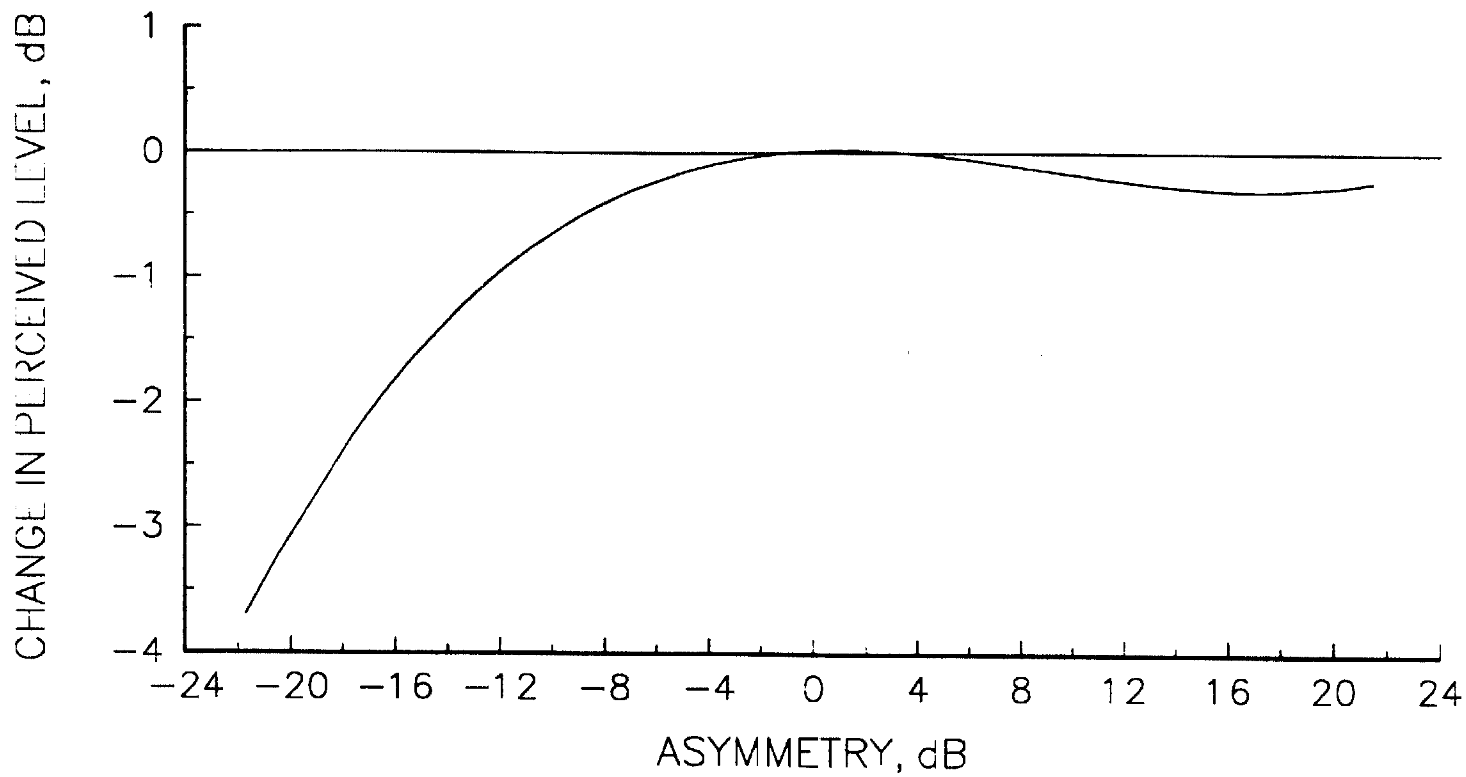


Figure 5.— Predicted N—wave asymmetry effect.

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13. ABSTRACT *(Maximum 200 words)* The NASA Langley Research Center's sonic boom apparatus was used in an experimental study to quantify subjective loudness response to a wide range of asymmetrical N-wave sonic boom signatures. Results were used to assess the relative performance of several metrics as loudness estimators for asymmetrical signatures and to quantify in detail the effects on subjective loudness of varying both the degree and direction of signature loudness asymmetry. Findings of the study indicated that Perceived Level (Steven's Mark VII) and A-weighted sound exposure level were the best metrics for quantifying asymmetrical boom loudness. Asymmetrical signatures were generally rated as being less loud than symmetrical signatures of equivalent Perceived Level. The magnitude of the loudness reductions increased as the degree of boom asymmetry increased, and depended upon the direction of asymmetry. These loudness reductions were not accounted for by any of the metrics. Corrections were determined for use in adjusting calculated Perceived Level values to account for these reductions. It was also demonstrated that the subjects generally incorporated the loudness components of the complete signatures when making their subjective judgments.

14. SUBJECT TERMS
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